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An econometric analysis of energy input–output in Turkish agriculture

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Abstract

This study analyzes energy use and investigates influences of energy inputs and energy forms on output levels in Turkish agriculture during the period 1975–2000. The output level was calculated in the form of annual grain equivalent at aggregate level for 104 agricultural commodities except livestock products. Output level was specified as a function of total physical, fertilizer and seed energy, and ordinary least squares was employed to estimate equation parameters. The results show that total energy input has increased from 19.6 GJ/ha in 1975 to 45.7 GJ/ha in 2000, whereas total output energy has risen from 27.1 GJ/ha to a level of 39.1 GJ/ha. Energy efficiency indicators, input–output ratio, energy productivity and net energy have declined over the examined period. Total physical and fertilizer energy, particularly nitrogen, significantly contributed to output level with elasticities of 0.24 and 0.14, respectively. The results also revealed that non-renewable, direct and indirect energy forms had a positive impact on output level. Moreover, Turkish agriculture has experienced a substantial increase in non-renewable energy use. This inefficient energy use pattern in the Turkish agriculture can create some environmental problems such as increase in global warming, CO_2 emissions, and non-sustainability. Thus, policy makers should undertake new policy tools to ensure sustainability and efficient energy use.

Keywords: Input–output ratio; Energy use; Energy forms; Energy input elasticities; Turkish agriculture

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1. Introduction

Nowadays, agricultural sector has become more energy-intensive in order to supply more food to increasing population and provide sufficient and adequate nutrition. However, considering limited natural resources and the impact of using different energy sources on environment and human health, it is substantial to investigate energy use patterns in agriculture.

In Turkey, even the importance of agriculture has been declining mainly due to growing service and industry sectors. In the last 20 years, agriculture has remained one of the vital sectors since it occupies large rural areas and has a significant influence on employment, GDP and exports. As of 2000, 35% of population lived in rural areas and 34.9% of the active population was employed in this sector. In addition, the shares of agriculture in GDP and export accounted for 12.9 and 7.1%, respectively [1].

The agricultural production system has changed profoundly in Turkey since use of mechanization, chemical fertilizers, high-yielding seeds and pesticides increased substantially, resulting in considerable changes in agricultural energy flows and more dependence on fossil fuel energy. This energy use pattern might have created problems in Turkey such as environmental and global warming as in most developing and developed countries. Thus, it is crucial to investigate energy use patterns and energy efficiency for alternative production systems. Although, there are numerous studies of energy use patterns in developed as well as developing countries [2–5], energy use in Turkish agriculture has generally received little attention [6–8]. However, only one of these studies [6] has

Nomenclature

ME	machine energy (MJ/ha)
G	weight of tractor (kg)
E	constant that is taken 158.3 MJ/kg for tractor
T	economic life of tractor (h)
C_a	effective field capacity (ha/h).
S	working speed (km/h)
W	working width (m)
E_f	field efficiency
Y	annual grain equivalent (10^6 kg)
TPE	total physical energy (10^{15} J)
FE	fertilizer energy (10^{12} J)
SE	seed energy (10^{12} J)
RE	renewable energy
NRE	non-renewable energy
DE	direct energy
IDE	indirect energy

investigated the energy use at the aggregate level in Turkish agriculture, by determining energy use for 36 commodities in Turkish agriculture for the period 1975–2000. The current study substantially extends previous research [6] in terms of modelling energy use for different energy sources and providing energy efficiency, net energy, energy sources.

The main objective of this study is to examine energy use pattern for 104 agricultural commodities during the same period. Furthermore, this study aims to explore the relationship between aggregate annual grain equivalent and energy inputs using various functional forms. In addition, the relationship is also examined for different energy sources in the form of renewable and non-renewable, direct and indirect energy. Once estimated, the models yield elasticities of energy inputs and energy sources for Turkish agriculture as well as a set of results that can be used by policy makers or other relevant agents in order to ensure sustainability and more efficient energy use.

2. Data

The data used in this study were based on annual data for the period 1975–2000 and were obtained from numerous sources. Data on agricultural population and seed use for selected crops were collected from the FAO statistical database [9]. Number of animals and tractors, electricity consumption and fertilizer use in agriculture were gathered from publications of the State Planning Organization and State Institute of Statistics of Turkey [10–13]. In this study, 104 agricultural commodities excluding livestock and six major inputs were considered (see Appendix A).

In order to calculate input–output ratios and other energy indicators, the data were converted into output and input energy levels using equivalent energy values for each

commodity and input (Appendix B). Energy inputs included in this study are total physical, fertilizer and seed energy. Total physical energy consisted of human, animal, machinery (tractor manufacturing–repair), electricity and diesel energy. Human energy in agriculture was calculated assuming that each person works 210 days a year and 8 h a day. For animal energy, working hours of animals used in agricultural production activities was taken as 360 h annually [5,14]. The following formula was used to calculate annual tractor manufacturing and repair energy per hectare:

$$\mathrm{ME} = (G \times E)/(T \times C_a) \tag{1}$$

where ME is the machine energy (MJ/ha), G the weight of tractor (kg), E a constant taken 158.3 MJ/kg for tractors, T the economic life of tractor (h) and: C_a the effective field capacity (ha/h), calculated as

$$C_a = (S \times W \times E_f)/10 \tag{2}$$

where S is the working speed (km/h), W the working width (m), and E_f the field efficiency, assuming a 2500 kg single-wheeled, 40-kW power tractor with 60–70 hp [15]. The electrical energy data refers to total energy used in agriculture since it was not possible to separate the consumption of electricity for purposes other than agricultural production due to lack of data. Mechanical energy was calculated on a fuel consumption basis assuming that a tractor (40 kW) consumes 4.8 l diesel per hour with a 40% loading capacity [16] and that its average use is 720 h annually [17].

Fertilizer is one of the most significant inputs that impact on yield level and most is used in nitrogen, phosphorus and potassium forms [18]. For this reason, we considered these fertilizer forms to calculate total fertilizer energy input. One of the other essential inputs is seed for agricultural production. Fertilizer and seed energy were calculated by multiplying the quantities with their corresponding energy conversion factors (Appendix B). The aggregate annual grain equivalent and output energy for relevant agricultural commodities were determined using conversion factors for each commodity.

3. Method

Realizing that output is a function of inputs, production function can be expressed as $Y = F(X_{it})$ where Y is output level, X_{it} is a vector of input variables that affect output such as fertilizer, seed and diesel and t is a time subscript.

In order to estimate this relationship, a mathematical function needs to be specified. For this purpose, several functions were tried, and the Cobb–Douglas production function was chosen since it produced better results among the others. The Cobb–Douglas production function is expressed in general form as follows [19]

$$\ln Y_t = \ln \beta_0 + \sum_{i=1}^{n} \beta_i \ln(X_{it}) + \varepsilon_t \tag{3}$$

where β_0 is a constant, β_i denotes coefficients, and ε_t is the error term, assumed normally distributed with mean 0 and constant variance σ^2.

The dependent variable Y was taken as annual grain equivalent at aggregate level for the examined agricultural commodities, and was specified as a function of total physical, fertilizer and seed energy. It is obvious that there are numerous variables influencing output level such as prices of inputs and outputs and agricultural policies. However, it was not possible to capture these variables due to aggregation problems and lack of sufficient data. Total physical energy consisted of human, animal, electricity, diesel and tractor manufacturing–repair. In addition to these variables, a time trend is included in the empirical model to account for technical change in the estimation period. Following this explanation, Eq. (3) can be given as

$$\ln Y_t = \ln \beta_0 + \beta_1 \ln \mathrm{TPE}_t + \beta_2 \ln \mathrm{FE}_t + \beta_3 \ln \mathrm{SE}_t + \beta_4 T + \varepsilon_t \tag{4}$$

where Y is the annual grain equivalent (10^6 kg), TPE is the total physical energy (10^{15} J), FE is the fertilizer energy (10^{12} J), SE is the seed energy (10^{12} J) and T is the time trend variable.

The study was also aimed at investigating the relationship between output and different energy forms. More specifically, we considered different energy forms as renewable or non-renewable, as direct or indirect. Indirect energy consists of the pesticide, fertilizer and direct energy including human power, diesel and electricity energy used in the production process. On the other hand, non-renewable energy includes petrol, diesel, electricity, chemicals, fertilizers and renewable energy consists of human and animal. As a functional form, the Cobb–Douglas production function was selected and specified in the following forms

$$\ln Y_t = \ln \eta_0 + \eta_1 \ln \mathrm{RE}_t + \eta_2 \ln \mathrm{NRE}_\mathrm{t} + \eta_3 T + \varepsilon_t \tag{5}$$

$$\ln Y_t = \ln \gamma_0 + \gamma_1 \ln \mathrm{DE}_t + \gamma_2 \ln \mathrm{IDE}_t + \gamma_3 T + \varepsilon_t \tag{6}$$

where RE and NRE denote renewable and non-renewable energy forms, respectively. DE represents direct energy and IDE denotes indirect energy. All estimations were carried out using the Shazam 8.0 software program [20].

4. Results

4.1. Energy use for crop production

In order to calculate physical energy inputs, inputs used in the agricultural sector were segregated depending on human, animal and mechanical sources. Throughout the period 1975–2000, Turkish agriculture sector has experienced a significant change in terms of physical input usage. The total physical power rose from 65.3 to 97.1 million hp, or by nearly 33%. The shares of human and animal physical power in agriculture diminished over the period examined from 27–58 to 19–24%, respectively, whereas mechanical power showed a tremendous increase. The share of mechanical power increased more than three-fold, from 14% in 1975 to 57% in 2000.

During the investigation period, total physical energy used in agriculture (Table 1) increased gradually from 164.2×10^{15} J in 1975 to 417.7×10^{15} J in 2000. In terms of

Table 1
Estimated physical energy input

Years	Human energy (10^{15} J)	Animal energy (10^{15} gJ)	Tractor manu-facturing and repair energy	Electricity (10^{15} J)	Diesel (10^{15} J)	Total physical energy input (10^{15} J)
1975	76.6	33.6	1.4	5.3	47.3	164.2
1976	76.6	34.2	1.4	5.4	54.8	172.5
1977	76.6	34.7	1.5	5.5	62.4	180.6
1978	76.5	35.3	1.5	5.6	72.1	190.8
1979	76.3	36.4	1.5	6.4	85.7	206.3
1980	76.1	36.9	1.5	6.7	84.9	206.1
1981	76.6	36.8	1.5	7.2	89.3	211.4
1982	77.0	33.4	1.5	7.8	95.6	215.3
1983	77.5	32.3	1.5	8.0	99.9	219.3
1984	77.9	28.4	1.5	9.1	108.4	225.2
1985	78.4	28.4	1.6	13.4	113.6	235.4
1986	79.0	28.8	1.6	14.0	119.2	242.5
1987	79.5	28.6	1.6	17.1	124.1	250.9
1988	80.1	28.1	1.7	18.2	127.4	255.5
1989	80.6	27.1	1.7	19.9	130.9	260.2
1990	81.0	25.2	1.7	24.7	134.8	267.3
1991	81.0	26.2	1.6	30.6	137.1	276.5
1992	81.0	26.0	1.7	36.9	141.3	286.8
1993	80.9	25.6	1.7	42.5	145.2	295.9
1994	80.8	25.4	1.6	51.3	147.4	306.6
1995	80.6	24.9	1.6	65.0	151.2	323.3
1996	80.4	24.9	1.6	78.4	157.1	342.4
1997	80.2	23.2	1.6	86.4	170.3	361.7
1998	79.9	22.8	1.6	100.8	175.6	380.8
1999	79.6	22.6	1.6	112.7	179.9	396.4
2000	79.2	21.8	1.6	131.8	183.3	417.7
Average	78.9	28.9	1.6	35.0	120.7	265.1

energy sources, human, animal and mechanical energy consumed 47, 20 and 33% of total physical energy input in 1975. However, the shares of human and animal energy inputs in total physical input energy decreased to 19 and 5% in 2000, respectively. On the other hand, the share of mechanical energy input rose to 76% in 2000. The increase in mechanical energy mainly resulted from the high consumption of diesel and electricity which rose by about four and twenty-five times, respectively. The changing consumption pattern of physical energy use can be attributed to an increase in the technology level and the number of tractors, reflected in more diesel consumption. During the 25 years, the number of tractors grew from 243 thousand in 1975 to 942 thousand in 2000, an annual growth rate of 5.6%. This increase in mechanization level is one of the main factors decreasing human and animal usage in Turkish agriculture.

Fertilizer use in terms of quantity and energy equivalence for the examined period is given in Table 2. As can be seen from this table, total fertilizer input energy has showed significant increases, rising from $135{,}765\times10^{12}$ J in 1975 to $467{,}996\times10^{12}$ J in 2000. Nitrogen is the most significant fertilizer and its consumption increased around 3.75-fold in the studied period, with an annual average of 4788 thousand tonnes. Nitrogen is

Table 2
Quantities and energy values of fertilizer

Years	N (000 tons)	N energy (10^{12} J)	P_2O_5 (000 tons)	P_2O_5 energy (10^{12} J)	K_2O (000 tons)	K_2O energy (10^{12} J)	Total fertilizer energy (10^{12} J)
1975	1750.2	11,2712.0	1909.8	22,841.3	31.6	211.9	135,765.1
1976	2812.7	181,137.2	3069.8	36,714.3	62.2	416.6	218,268.1
1977	3169.2	204,098.5	3368.6	40,288.9	39.1	262.3	244,649.6
1978	3697.2	238,099.6	3735.2	44,672.9	41.6	278.8	283,051.3
1979	3709.2	238,874.4	3881.1	46,417.5	75.7	507.5	285,799.5
1980	3038.6	195,683.6	2839.9	33,965.7	89.0	596.2	230,245.5
1981	3697.2	238,098.5	2913.6	34,846.4	75.4	504.9	273,449.7
1982	4034.5	259,820.5	3350.7	40,074.7	66.6	446.5	300,341.8
1983	4718.1	303,847.0	3635.1	43,476.4	49.1	329.2	347,652.6
1984	4754.2	306,171.2	3380.8	40,433.8	62.9	421.3	347,026.3
1985	4383.7	282,307.6	2800.1	33,488.9	67.8	454.3	316,250.7
1986	4539.0	292,308.9	3056.9	36,560.8	94.7	634.2	329,503.9
1987	5435.8	350,062.3	3440.1	41,143.9	101.5	679.8	391,886.0
1988	5149.6	331,633.4	2881.1	34,457.8	83.7	560.8	366,652.0
1989	5429.7	349,672.6	3524.0	42,146.6	116.0	777.4	392,596.6
1990	5711.6	367,827.4	3671.1	43,906.0	126.8	849.6	412,583.0
1991	5254.7	338,404.9	3631.5	43,432.9	95.1	636.8	382,474.6
1992	5742.7	369,828.6	3866.1	46,238.0	126.7	848.6	416,915.2
1993	6356.9	409,381.5	4623.2	55,294.0	169.9	1138.6	465,814.1
1994	4792.3	308,622.9	2610.6	31,223.2	112.6	754.4	340,600.5
1995	5016.6	323,069.4	3405.4	40,729.1	134.2	899.0	364,697.6
1996	5462.7	351,798.3	3395.6	40,611.7	146.8	983.8	393,393.9
1997	5555.7	357,790.0	3477.1	415,85.7	133.0	890.9	400,266.7
1998	6641.0	427,677.3	4127.8	49,369.1	177.0	1186.0	478,232.4
1999	7072.8	455,489.7	3751.2	44,863.8	161.4	1081.0	501,434.5
2000	6563.3	422,675.2	3697.4	44,220.4	164.2	1100.1	467,995.7
Average	4788.0	308,349.7	3386.3	40,500.1	100.2	671.2	349,521.0

followed by potassium and phosphorus with a 5.2 and 1.94-fold increases and the annual average consumption of phosphorus and potassium was realized as 3386 and 100 thousand tonnes, respectively. For the same period, the share of nitrogen in the total fertilizer energy input increased from 83 to 90.3% while the share of phosphorus shrunk from 16.8 to 9.4%, and that of potassium stayed almost constant.

Although some fluctuations were observed, the amount of total output energy also showed an increase, from 506×10^{15} to 819×10^{15} J, indicating a 38.2% increase. Energy inputs and output values were also calculated on a per hectare basis and are presented in Table 3. The cultivated area in Turkey increased from 18.7 million hectare in 1975 to 21.0 million hectare in 2000. However, the agricultural area almost stabilized after 1987. Total energy input more than doubled, from 19.6 to 45.7 GJ/ha. This finding implies that Turkish agriculture has become more input-intensive, mainly due to the contribution of total fertilizer (particularly nitrogen), electricity and diesel.

Fertilizer and physical energy inputs an average consumed 16.8 and 12.8 GJ/ha. In other words, the shares of these inputs in total energy use on a per hectare basis were 50.9 and 38.8%, respectively. Of the total fertilizer, nitrogen energy ranked first place (90%)

Table 3
Energy input and output values in Turkish agriculture (GJ/ha)

Years	Area sown (million hectare)	Estimated physical energy input						Fertilizer energy	Seed energy	Total input energy	Total output energy
		Human	Animal	Tractor manufacturing and repair energy	Electricity	Diesel	Total				
1975	18.7	4.1	1.8	0.1	0.3	2.5	8.8	7.3	3.5	19.6	27.1
1976	19.0	4.0	1.8	0.1	0.3	2.9	9.1	11.5	3.5	24.0	29.6
1977	19.2	4.0	1.8	0.1	0.3	3.3	9.4	12.8	3.4	25.6	29.0
1978	19.0	4.0	1.9	0.1	0.3	3.8	10.0	14.9	3.5	28.4	29.5
1979	19.4	3.9	1.9	0.1	0.3	4.4	10.6	14.7	3.5	28.8	29.9
1980	19.2	4.0	1.9	0.1	0.3	4.4	10.8	12.0	3.4	26.2	29.6
1981	19.5	3.9	1.9	0.1	0.4	4.6	10.9	14.0	3.5	28.4	30.5
1982	19.7	3.9	1.7	0.1	0.4	4.9	10.9	15.3	3.4	29.6	32.2
1983	20.0	3.9	1.6	0.1	0.4	5.0	11.0	17.4	3.4	31.9	30.1
1984	20.2	3.9	1.4	0.1	0.4	5.4	11.2	17.2	3.4	31.7	31.1
1985	20.7	3.8	1.4	0.1	0.6	5.5	11.4	15.3	3.4	30.1	30.3
1986	20.9	3.8	1.4	0.1	0.7	5.7	11.6	15.8	3.2	30.6	33.0
1987	21.5	3.7	1.3	0.1	0.8	5.8	11.7	18.2	3.2	33.1	33.0
1988	21.7	3.7	1.3	0.1	0.8	5.9	11.8	16.9	3.3	31.9	34.3
1989	21.8	3.7	1.2	0.1	0.9	6.0	11.9	18.0	3.2	33.1	28.3
1990	21.7	3.7	1.2	0.1	1.1	6.2	12.3	19.0	3.2	34.6	34.2
1991	21.6	3.8	1.2	0.1	1.4	6.4	12.8	17.7	3.3	33.8	34.8
1992	21.6	3.7	1.2	0.1	1.7	6.5	13.3	19.3	3.1	35.7	33.4
1993	21.8	3.7	1.2	0.1	2.0	6.7	13.6	21.4	3.3	38.2	34.8
1994	21.5	3.8	1.2	0.1	2.4	6.8	14.2	15.8	3.7	33.7	31.7
1995	21.2	3.8	1.2	0.1	3.1	7.1	15.3	17.2	3.7	36.2	33.5
1996	21.3	3.8	1.2	0.1	3.7	7.4	16.1	18.4	3.7	38.2	35.3
1997	21.3	3.8	1.1	0.1	4.1	8.0	17.0	18.8	3.6	39.4	35.9
1998	21.5	3.7	1.1	0.1	4.7	8.2	17.7	22.3	3.5	43.5	39.7
1999	21.2	3.8	1.1	0.1	5.3	8.5	18.7	23.7	3.4	45.8	35.3
2000	21.0	3.8	1.0	0.1	6.3	8.7	19.9	22.3	3.4	45.7	39.1
Average	20.6	3.8	1.4	0.1	1.7	5.8	12.8	16.8	3.4	33.0	32.5
%		11.6	4.3	0.3	5.0	17.6	38.8	50.9	10.3	100.0	

followed by phosphorus and potassium. Diesel and electricity were found as the two major energy inputs accounting for 45 and 13% of physical energy. The seed used in this study included cereals, pulses, tubers and oilseeds, and total grain equivalent value for seed increased from 4478.9×10^6 kg in 1975 to 4897.8×10^6 kg in 2000. Energy from seed was estimated on average 3.4 GJ/ha and was almost constant in the examined period.

The results imply that development in Turkish agriculture led to decreased human and animal energy but increased mechanization level and use of energy-intensive inputs. While the shares of human and animal energy in the total energy inputs were 20.9 and 9.2% in 1975, these decreased to 8.3 and 2.2% in 2000, respectively. Even if the increase in energy input was realized, energy intensity fluctuated for some years (Fig. 1). However, the energy consumption by sources showed almost linear relationship, the energy input on per hectare basis decreased for the years of 1980 and 1994 mainly due to economic crises in Turkey.

During this 25 years period, total output energy increased from 27.1 to 39.1 GJ/ha with the 30.7% increase. Since all inputs were expressed in physical terms, efficiency refers only to energy conversion at the farm gate level. From Fig. 2, it can be concluded that input–output ratio and energy productivity have declined significantly over the 1975–2000 period. The input–output ratio was normalized as 1.00 on average fell from 1.38 in 1975 to 0.86 in 2000, with severe fluctuations in 1983, 1989 and 1999 mainly due to extreme drought conditions. Energy productivity also showed a diminishing trend. Net energy production value appeared to be mainly negative after 1983, especially in recent years.

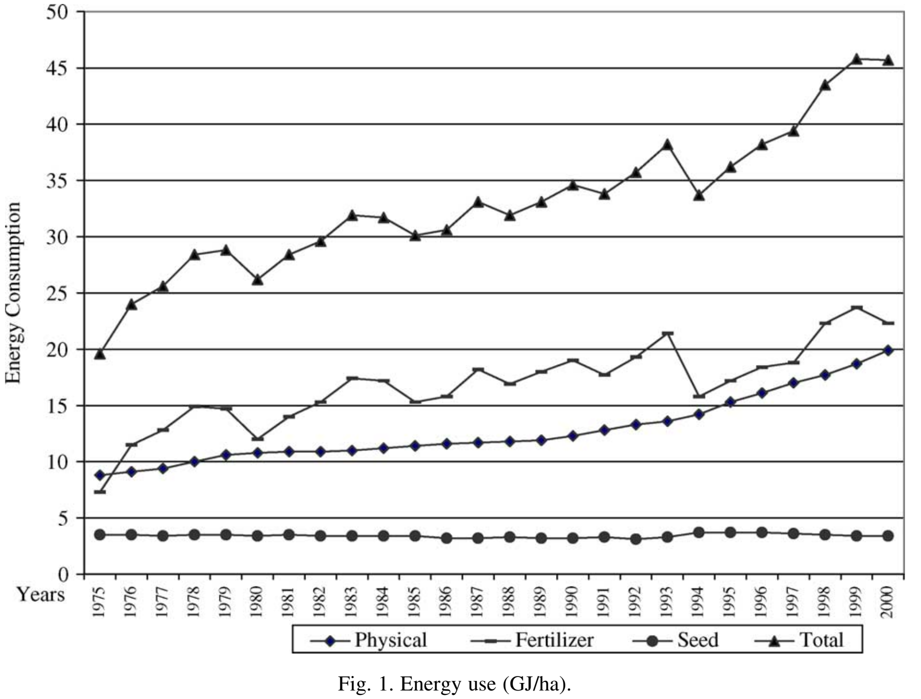

Fig. 1. Energy use (GJ/ha).

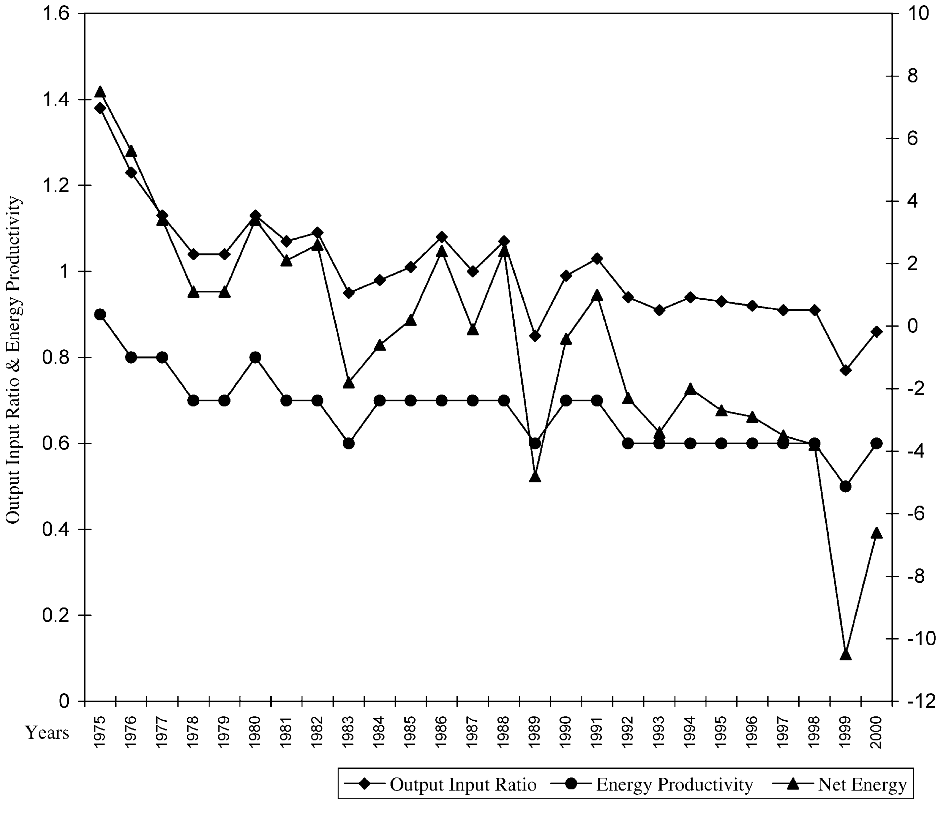

Fig. 2. Energy efficiency indicators.

These indicators imply that the output did not increase as much as in energy input use in Turkish agriculture.

In order to understand better the direction of agricultural energy use, it is important to investigate the tendency of energy forms. For this purpose, renewable and non-renewable energy forms used in the Turkish agriculture were also examined. As can be seen from Fig. 3, Turkish agriculture has been mainly dependent on non-renewable energy sources in the period examined. Furthermore, this dependency showed an increasing trend and the use of non-renewable energy sources was realized as a 72.8% increase. Renewable energy use decreased slightly for the relevant period.

4.2. The econometric results for energy use

One of the main objectives of this study was to explore the relationship between total output and energy inputs in some detail. For this purpose, Cobb–Douglas production function was specified and estimated using ordinary least square estimation technique. One of the features of this production function is that estimated coefficients represent elasticities. Furthermore, Cobb–Douglas production function imposes a priori restrictions

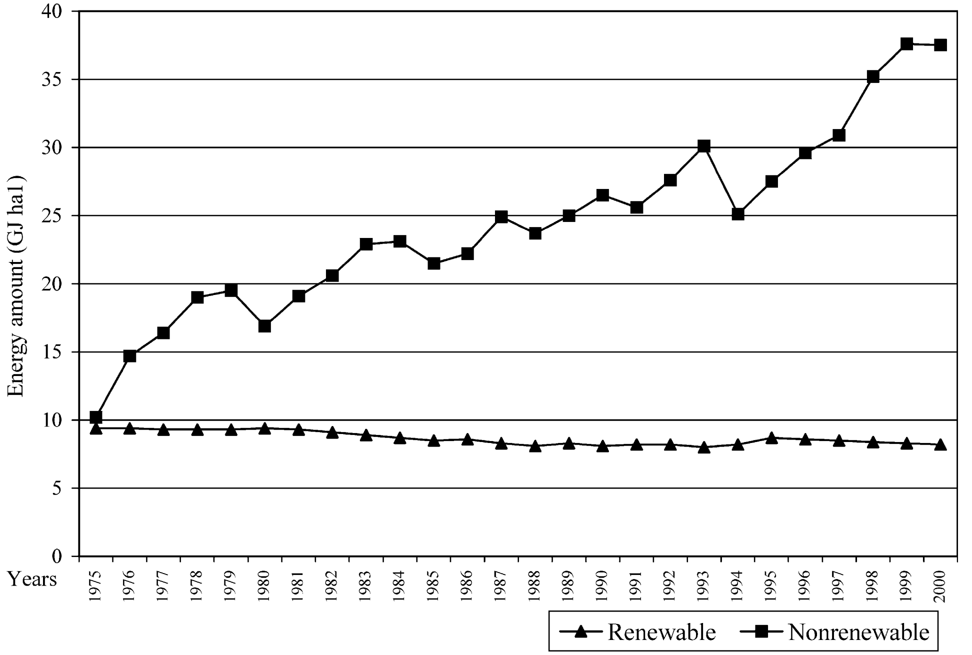

Fig. 3. Renewable and non-renewable energy.

on patterns of substitution among inputs. In particular, elasticities of substitution among all inputs must be equal to unity. From the view point of output–input ratios, higher input use, ceteris paribus, is bound to mean lower partial productivity or efficiency, if estimated coefficient is less than one.

Eqs. (4)–(6) were estimated using ordinary least squares estimation and the results are provided in Table 4.

Since time series data were used in this study, autocorrelation might be a potential concern, and therefore needed to be tested, using the Durbin–Watson test. Computed Durbin–Watson values were calculated as 2.30, 2.48 and 2.35 for Eqs. (4)–(6), showing that there was no autocorrelation at the 5% significance level in the estimated models. The R^2 values were calculated as 0.89, 0.88 and 0.89 for Eqs. (4)–(6), indicating that around 89% of the variability in the total annual grain equivalent was explained by these models.

As shown in Table 4, all parameters in Eq. (4) except that for seed energy were statistically significant. The elasticity of total physical energy was estimated as 0.24 implying that a 10% increase in total physical energy would lead to a 2.4% increase in total grain equivalent. The fertilizer parameter has an elasticity of 0.14, indicating a change in the fertilizer energy by less than the amount of change in the total output. In other words, this finding suggests that total output was responsive to fertilizer energy in the Turkish agriculture. However, the elasticities of total physical and fertilizer energy are estimated as inelastic since some variables such as human capital are omitted in the model due to lack

Table 4
Econometric estimation results

Variables	Coefficient	t-Ratio
Eq. (4): $\ln Y_t = \ln \beta_0 + \beta_1 \ln \mathrm{TPE}_t + \beta_2 \ln \mathrm{FE}_t + \beta_3 \ln \mathrm{SE}_t + \beta_4 T + \varepsilon_i$		
Constant	8.07	4.97*
Total physical energy	0.24	2.35*
Total fertilizer energy	0.14	1.94***
Seed energy	0.10	0.23
Time trend	0.002	1.82***
Durbin–Watson	2.30	
R^2	0.89	
Eq. (5): $\ln Y_t = \ln \eta_0 + \eta_1 \ln \mathrm{RE}_t + \eta_2 \ln \mathrm{NRE}_t + \eta_3 T + \varepsilon_i$		
Constant	11.58	3.47*
Renewable Energy	−0.41	-0.66
Non-renewable energy	0.18	1.98***
Time trend	0.009	2.21*
Durbin–Watson	2.48	
R^2	0.88	
Eq. (6): $\ln Y_t = \ln \gamma_0 + \gamma_1 \ln \mathrm{DE}_t + \gamma_2 \ln \mathrm{IDE}_t + \gamma_3 T + \varepsilon_i$		
Constant	8.18	21.94*
direct energy	0.24	2.98*
Indirect energy	0.19	2.12**
Time trend	0.002	1.81***
Durbin–Watson	2.35	
R^2	0.89	

*, ** and *** indicate significance at 1, 5 and 10% levels, respectively.

of sufficient data. Time trend variable was found statistically significant at the 10% significance level, implying that technological change occurred over 25 years due mainly to usage of high quality inputs such as seeds and fertilizers.

The impact of renewable, non-renewable and direct and indirect energy on output was investigated by estimating Eqs. (5) and (6). The estimated coefficients, t values and other statistics are given in Table 4. The results showed that the non-renewable energy variable had the expected sign and was statistically significant, with an elasticity value of 0.18. On the other hand, decreasing renewable energy use in the Turkish agriculture is also reflected in the model, in that this variable was estimated statistically insignificant with a negative sign.

Regarding the impact of direct and indirect energy on the output level, regression results revealed that both parameters are statistically significant and have positive signs. The elasticity estimates of direct and indirect energy were found as 0.24 and 0.19, respectively (Table 4). These elasticity measures suggest that annual grain equivalent increased less than proportionate to these energy forms changes.

5. Summary and conclusions

This study was aimed at analysing the input–output relationships in Turkish agriculture for the period 1975–2000. For this purpose, total physical, fertilizer, seed and output

energies were estimated, and the energy use pattern was examined in the form of direct indirect and renewable, non-renewable energy classifications. Furthermore, the relationship between total output and energy inputs was explored using functional models.

The results showed that total input energy value increased from 19.6 GJ/ha in 1975 to 45.7 GJ/ha in 2000. The shares of animal and human energy decreased, but electricity and diesel showed an increase in the total physical energy over the examined period. The inputs of human and animal declined sharply, a result of the industrialization of Turkish agriculture resulting in a substitution of machinery for human and labour. On the other hand, fertilizer energy (mostly nitrogen) increased, while seed energy was almost stable. These results revealed that Turkish agriculture has become more input energy-intensive. High input energy use in the agricultural production caused an increase in the output energy level rising from 27.1 GJ/ha in 1975 to a level of 39.1 GJ/ha in 2000.

The results also showed that partial productivity of energy use in Turkish agriculture has declined even if production has increased significantly. The input–output ratio decreased from 1.38 to 0.86 in the examined period. Similarly, energy productivity and net energy indicators also declined. The study indicated that total input energy has increased 2.3-fold but the output energy increased only 1.4-fold over the examined period. This means that output did not increase as much as in energy input use in Turkish agriculture. Also, it is noteworthy that Turkish agriculture has become heavily dependent on non-renewable energy sources. This result is consistent with a previous study conducted in Turkey [6]. Input and output energy levels per hectare increased from 17.4 and 38.8 GJ/ha in 1975 to 47.4 and 55.8 GJ/ha in 2000, respectively. Furthermore, input–output ratio was estimated as 2.23 in 1975 and 1.18 in 2000.

Econometric estimation results showed that physical and fertilizer energy had a positive impact on annual grain level, and elasticities of these inputs were estimated as inelastic. In terms of energy forms, the empirical results revealed that the effects of direct, indirect and non-renewable energy forms on annual grain level were estimated as statistically significant, whereas renewable energy was found to be statistically insignificant with a negative sign.

All these findings show that energy use in the Turkish agriculture has significantly increased over the last 25 years. This increased energy use has brought some environmental concerns such as global warming and increase in CO_2 emissions. It is possible to increase agricultural production by raising partial productivity of energy inputs without depending on mainly non-renewable energy sources that create severe environmental problems. Therefore, policy makers should take the necessary measurements to ensure more environmental friendly energy use patterns in the Turkish agriculture.

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Appendix A. List of agricultural commodities

All commodities

Cereals	Wheat, barley, rye, millet, spelt, canary grass, mixed grain, maize, rice, oats
Pulses	Broad beans, peas, kidney beans, wild vetches, dry beans, cow vetches, lentil, chick peas
Industry crops	Aniseed, poppy (capsule), hemp (fibre), flax (fibre), cotton (lint), sugarbeet, tobacco, tea
Oilseed	Safflower, sunflower, poppy (seed), hemp (seed), flax (seed), rapeseed, soybeans, sesame, groundnuts, cotton seed
Tuber crops	Beets for fodder, dry garlic, dry onions, potatoes
Vegetables	
Leguminous vegetables	Green broad beans, calavence, green beans, green peas
Fruit bearing vegetables	Pumpkin, squash, okra, tomatoes, stuff pepper, green pepper, cucumber, eggplant, melon, water melon
Root, bulb and tuberous vegetables	Carrots, Jerusalem artichokes, green garlic, green onion, horseradish, red radish
Leafy and edible vegetables	Artichokes, celery, spinach, leek, cabbage, black cabbage, leaf lettuce, head lettuce, garden orache, purslane
Others	Cauliflowers, Asparagus
Fruits	
Nuts	Pistachios, almonds, walnuts, hazelnuts, chestnuts
Stone fruits	Plums, jujube, apricot, cornel, cherries, peaches, sour cherries, wild apricots, olive
Grapes, etc.	Mulberry, figs, carobs, strawberries, bananas, pomegranates, persimmons, grapes
Pome fruits	Pears, quinces, apples, medlar, loquats
Citrus	Lemon, mandarins, oranges, sour oranges, grapefruit

Appendix B. Energy equivalents of inputs and outputs

	Equivalent energy (MJ)	
Input		
Human labour (h)	2.30	0.9 hp
Animal labour		
Horse (h)	10.10	3.80 hp
Mule (h)	4.04	1.50 hp
Donkey (h)	4.04	1.50 hp
Cattle (h)	5.05	1.90 hp
Water buffalo (h)	7.58	5.70 hp
Electricity (kW h)	11.93	
Diesel (l)	56.31	
Chemical fertilizers		
Nitrogen (kg)	64.40	
P_2O_5 (kg)	11.96	
K_2O (kg)	6.70	

(*continued on next page*)

Appendix B (*continued*)

	Equivalent energy (MJ)
Seeds	
Cereals (kg)	25.0
Pulses (kg)	25.0
Oil seed (kg)	3.60
Tuber (kg)	14.70
Output	
Commodities	
Cereals (kg)	14.70
Pulses (kg)	14.70
Industry crops	
Sugar beet (kg)	5.04
Tea (kg)	0.80
Tobacco (kg)	0.80
Others (Cotton, etc.) (kg)	11.80
Oilseed (kg)	25.0
Tuber crops	
Potatoes (kg)	3.60
Others (kg)	1.60
Vegetables (kg)	
Leguminous vegetables (kg)	1.90
Fruit bearing vegetables (kg)	0.80
Water melon/melon (kg)	1.90
Root, bulb and tuberous vegetables (kg)	1.60
Leafy and edible vegetables (kg)	1.20
Others (kg)	1.60
Fruits	
Nuts (kg)	11.80
Stone fruits (kg)	1.90
Grapes, etc. (kg)	11.80
Pome fruits (kg)	1.90
Citrus (kg)	1.90

(*continued on next page*)

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